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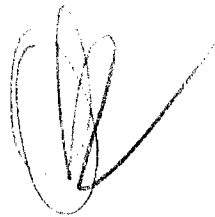
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KINETICS OF AUSTENITE GRAIN GROWTH IN ELECTROSLAG WELDING

by G. V. Nazarov

- USSR -



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KINETICS OF AUSTENITE GRAIN GROWTH IN ELECTROSLAG WELDING

- USSR -

[Following is a translation of an article by G. V. Nazarov, Engineer, Krasnoye Sormovo Plant, in the Russian-language periodical Svarochnoye Proizvodstvo (Welding Production), No 12, Moscow, December 1963, pp 10-12.]

Thermal cycle processes of points in the heat-affected zone during electroslag welding are determined. Kinetics of grain growth of austenite in the process of welding are studied and the relationship between grain growth and structure and mechanical properties in the heat-affected zone are established.

The present work was carried out in 1960-1961 by the Krasnoye Sormovo Plant and the Institute of Metallurgy Imeni A. A. Baykov. It was part of a series of investigations devoted to a study of the processes occurring in the heat-affected zone during electroslag welding and subsequent heat treatment of medium-alloy steels.

The process of austenite transformation in the heat-affected zone during electroslag welding of pearlitic steels leads to formation of undesirable structures which results in a significant increase of hardness, drop of impact strength, and brittle fracture I. These properties are lower in the heat-affected zone than in the base metal after welding. For restoration of the initial properties of the base metal to the heat-affect zone, the weld joint from medium-alloy steels is quenched in water or oil and tempered according to specifications for the base metal.

Certain indices of mechanical properties of the seam metal after welding may also be somewhat lower than the properties of the base metal.

As a result of conducted investigations 2, 3, 4 means

of obtaining adequately high mechanical and operating properties are noted. However, these methods of improvement the properties of the heat-affected zone have not still been developed. The only method at present is heat treatment of the entire weld joint.

For weldments which operate under very low dynamic loads, it is possible to simplify subsequent heat treatment to only high-temperature tempering [5]. After selecting a definite relationship of the indices of the mechanical properties of base metal, heat-affected zone, and seam metal in accordance with prerequisites of work [16] in separate case [6] it is possible to eliminate subsequent heat treatment upon satisfactory efficiency of the entire weldment.

Limitations of the above-stated technological variants is determined by the peculiarity of the electroslog process which does not permit regulation of the thermal cycle parameters of the heat-affected zone over wide limits and also by the lack of knowledge of heating and cooling principles during electroslog welding and those processes occurring in the heat-affected zone especially in direct proximity of the melting line.

The first work directed toward a study of the conditions of heating and cooling during electroslog welding is [7], which is the main topic, "Distribution of Heat in the Base Metal," of monograph [5].

Thermal cycles [8, 9] and temperature field [10] were determined for certain materials and thicknesses by a somewhat unique method. In all these works the maximum temperature (T_{\max}) of points in the heat-affected zone, as a rule, did not exceed 1000 C. In [7], only 2 points had $T_{\max} = 1100$, while in [8] there were two points with $T_{\max} = 1050$ and one point -- 1100. Only in [9] are 2 cycles with $T_{\max} = 1350$ C given and a series of cycles with T_{\max} above 1000 C was obtained by extrapolation. However, conditions of welding in the last work were essentially different from those in the present work. Thermal cycles of points lying in close proximity to the melting line with $T_{\max} =$ ranging from 1000 C to the melting point ($T_{m.p.}$) present practical interest as undesirable structure transformations in many respects are determined by heating and cooling conditions in this region. According to the principle of local effect [11] for calculating temperature field in welding in regions at distances equal to the size of the region taken as a reference, it is possible to replace the distributed heat source applied at its center of gravity to a concentrated source of equal potential. In our case, the slag bath was not able to be represented in the form of a simple concentrated source of heat. Therefore, to use the thermal theory in [11], additional information characterizing the slag bath as a heat source and conditions of cooling is

necessary.

Considering the above-state points, thermal cycles of points lying near the melting line were constructed first of all in the present work.

Welding conditions and some properties of steels are given in works [1, 2]. Feature of the applied technology is the use of low-alloy welding materials. Multicomponent alloying of seam metal is accomplished by means of melting the edges of the base metal, part of which constituted 50-60%. From this condition the optimum parameters of welding conditions were obtained.

Assembly of ingots in industrial conditions is done using plates (5x28x28 mm) placed with an internal spacing of 5-6 pieces per meter of weld joint. This arrangement does not allow to form an internal surface of the seam with the moving copper contact, therefore, copper supports are placed along the entire length of the weld joint. Electroslag welding was done with an A-372p unit with a 3-mm diameter electrode situated in the center of the weld joint without transverse oscillations in the welding process.

Conditions of heating during welding are characterized by the following parameters: welding current, 440-460 amps; voltage, 46-48 v; depth of slag bath, 40-60 mm, average speed of unit, 0.026 cm/sec. Specific linear energy (9/48) is 31,700 cal/cm²

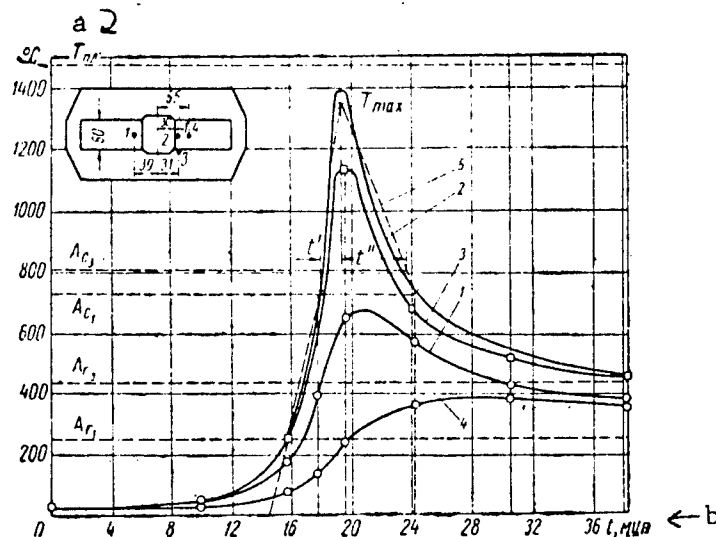


Fig. 1. Thermal cycles of points during electroslag welding: 1, 2, 3, 4, -- thermal cycles of corresponding points; 5--simulated cycle; a-- $T_{m.p.}$; b--time (min)

Thermal cycles of points in the heat-affected zone were measured with chromel-alumel thermocouples with points of insertion shown in Fig. 1. Technology of assembly and welding of

experimental plates and their dimensions were, at most, approximate to industrial conditions. During welding of two plates (60x200x500 mm), each plate had thermocouples placed in the center of the plate.

Temperature recording was done with six-point type SG galvanometer and an eight-loop MPO-2 oscillograph.

Analysis of the obtained thermal cycles shows that the character of change of basic parameters (T_{max} , t' , t'' , $W_{cool.}$) follow the general principles presented in work [11] for thermal cycling of the heat-affected zone in single-pass welding. It can be particularly noted that these parameters are similar to the case of automatic submerged-arc welding in work [13]. In [14] it was established that size of austenite grains has functionally increasing dependence on maximum temperature of cycling, holding time at a temperature higher than A_{c3} during heating (t') and cooling (t''). Consequently, the cycle of point 2, for which these parameters have the most meaning (see Fig. 1), is most favorable.

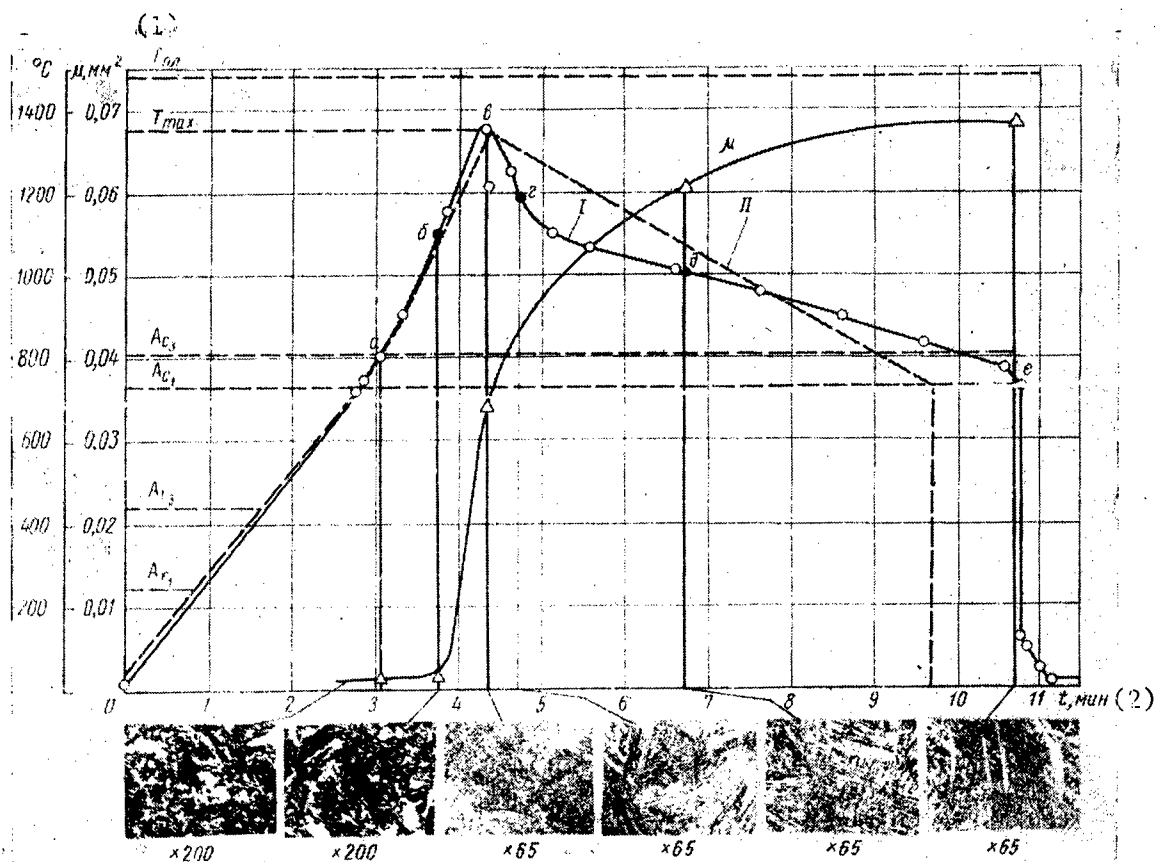


Fig. 2. Structure and properties of metal at various points of cycling: I--thermal cycle of samples simulated according to IMET-1; II--simulated cycle 1-- $T_{m.p.}$, 2--time (min)

In order to establish change of structure and mechanical properties of the base metal in the heat-affected zone at specific moments of heating and cooling by cycle 2, research was conducted according to the method of IMET-1.

Samples for mechanical tests and metallographic investigation (3x7x150 mm) were processed on an IMET-1 unit by simulated thermal cycling and quenched from the temperatures designated in Fig. 2 by points a, b, c, d, e, and f. Size of actual austenite grains was determined by average grain size produced upon quenching to the martensite structure.

On the basis of comparing grain sizes at points a, b, and c, it can be verified that during arc welding the most intense grain growth is observed at temperatures near to T_{max} .

Maximum rate of grain growth is observed between points b and c. When cooling, this rate gradually decreases but grain size continues to increase.

In our case, the essential effect is produced by parameter t'' . In the cooling process (see Fig. 2), the grain is almost doubled in size. In spite of more intense grain growth, as compared to arc process, the maximum point has not been reached. From comparison of grain sizes produced by holding a sample section (3x7 mm) for two hours at 1300 C with the size at the end of cycle (point f), it may be concluded that the grain is approximately 1/3 the size for conditions for isothermal growth at a temperature close to T_{max} .

Holding time of points of the heat-affected zone at a temperature above $A_{c3}(t'+t'')$ and cooling rate depend on magnitude of specific linear energy (q/\sqrt{s}) and on cooling conditions of the seam with forming devices.

Thus, if the above-considered cycle, produced by welding with water-cooled, copper linings, is characterized by $t'+t'' = 5.5$ minutes, then thermal cycling from the same temperature (1350 C) but done with uncooled graphite linings with a higher specific linear energy ($q/\sqrt{s} = 51,600$ cal/cm²) is characterized by $t'+t'' = 13$ minutes (Fig. 3).

Thus, the condition of heating and cooling the heat-affected zone during electroslog welding can change depending on conditions and equipment for cooling weld joint. However, one should consider the given diagrams of anisotropic transformations which make it possible to estimate the condition of obtaining the most favorable structures during decomposition of austenite.

Change of grain size and structure can be associated with change of mechanical properties of the metal. Thus, as samples of 3x7-mm section were cooled from high temperatures (above A_{c3}) in water, nonuniform structures were produced which were different from the actual structures of the heat-affected zone after electroslog welding. Samples, cooled from point c, have strength approximately 1.7 times higher and relative reduction

in area below the metal in the initial state.

Samples, cooled from point f, have larger grains than samples cooled from point c. However, if one were to compare their properties with similar properties of samples cooled from point c, then it is possible to establish that strength of the first is lowered by approximately 10% while ductility increase 1.5 times. These distinctions allow one to assume that homogenization of austenite and improvement of the grain boundaries has a favorable effect on ductility of an overheated metal. Upon inspection of structures corresponding to points d, e, and f, it is possible to establish that the boundary between grains becomes less pronounced. These results show the favorable changes in structure and the necessity to consider characteristics of the transformation process in the supercritical interval of temperatures of all three stages: formation of austenite throughout the entire volume, dissolving of carbide particles in the austenite, and subsequent homogenization of austenite.

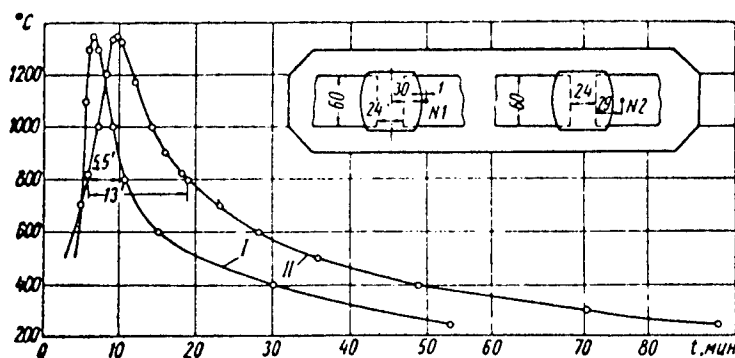


Fig. 3. Thermal cycles: I--welding on a copper support; II--welding on a graphite support; l--time (min)

Effect of changing the time of overheating at points of the heat-affected zone, occurring during changes of welding conditions and conditions of seam cooling by a forming device, on mechanical properties were investigated by testing the metal, subjected to the same thermal cycle, for impact strength.

For this purpose, ingots for impact samples measuring 12x12x55 mm were processed on special re-equipped butt-welding machines in cycles which simulated actual welding cycles as shown in Fig. 1. Cooling of samples was partially done while samples were in the machine and partially in the furnace, and water quenched from 250 C. Deviation of simulated cycles from

actual cycles up to 250 C did not exceed $\pm 10^\circ$.

Results of impact tests (see table below) show that samples heated according to cycle I have a small grain size but possess a much higher impact strength.

1 Цикл	2 Параметр цикла ($t' + t''$) в мин	3 Удельная погонная энергия в кал/см ²	4 Охлаждающая подкладка	5 Ударная вязкость в кг/см ²	
				6 в исходном состоянии	7 после отпуска
I	5,5	31 700	8 Медная	$\frac{2,8-5,0}{4,0}$	$\frac{5,8-6,2}{6,0}$
II	13,0	51 600	9 Графитовая	$\frac{2,2-5,0}{2,9}$	$\frac{2,5-4,8}{3,8}$

Key to table: 1--Cycle; 2--Parameter of cycle ($t' + t''$) in minutes; 3--Specific linear energy in cal/cm²; 4--Cooling support; 5--Impact strength in kg/cm²; 6--Initial state; 7--After tempering; 8--Copper; 9--Graphite.

Thus, two factors act on metal properties in the heat-affected zone: 1) grain growth, and, 2) increase of degree of homogenization and improvement of grain boundary state.

The first factor increases strength, ductility, and impact strength. The second factor does the opposite.

CONCLUSIONS

1. Thermal cycles for the case of electroslog welding of medium-alloy steels of 55-60 mm thickness on a copper cooling lining were plotted.

2. Kinetics of grain growth in the heat-affected zone under conditions of thermal cycling of electroslog welding were investigated. It is shown that control of grain size depends on parameters of the thermal cycle.

3. A higher degree of homogenization of austenite in comparison with arc welding is observed in line with grain growth, and state of the grain boundaries is also improved as revealed by quenching. Similar conditions improve mechanical properties of a metal, particularly, ductility.

4. Comparison of impact strengths of samples heated by two thermal cycles showed that impact strength is increased upon decrease of holding time in the supercritical interval, i. e. in the presence of smaller grains.

5. Selection of a more favorable thermal cycle is possible by changing the process and conditions of welding. For example, using a cooled copper lining and reduced linear energy, as compared with uncooled graphite lining, reduces holding time at temperatures above A_{c3} from 13.0 to 5.5 minutes.

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